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## High Data Rate Very Small Aperture Terminal Networking in Support of the New Attack Submarine

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<p>During the months of August and September 1996, the Fixed Surveillance System (FSS) program office of the Intelligence, Surveillance and Reconnaissance (ISR) Directorate of the Space and Naval Warfare Systems Command (SPAWAR) with the assistance of the Naval Research Laboratory (NRL) successfully demonstrated a high data rate (1.288 Mbps and higher) satellite network link in support of the New Attack Submarine (NSSN) Open System Critical Item Test (OSCIT). The satellite network link was established between the Naval Ocean Processing Facility (NOPF) in Dam Neck, VA and the NSSN test facility in Newport, RI. A direct sequence spread spectrum (DSSS) link as well as a narrowband Quadrature Phase-Shift Keying (QPSK) link were established using a commercial satellite transponder. The DSSS signal was transmitted using a Very Small Aperture Terminal (VSAT) having a 0.6 m articulated antenna and was received by a COMSAT Radiation Systems Inc. (CRSI) Triband Transportable Satellite Earth Terminal. The narrowband signal was transmitted from the earth terminal and received by the VSAT. The two simplex links were combined at the network layer via a router and provided TCP/IP wide area network (WAN) connectivity between two local area networks (LAN) over which COTS/GOTS Joint Maritime Command Information System (JMCIS) network applications were executed. The results showed that a full duplex network link could be operated using the VSAT and commercial technology to support high rate WAN connectivity between ship(s) and shore.</p>			
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# HIGH DATA RATE VERY SMALL APERTURE TERMINAL NETWORKING IN SUPPORT OF THE NEW ATTACK SUBMARINE

## 1. INTRODUCTION

In May 1996 the Department of Defense (DoD) published two reports: 1) *Defense Science and Technology Strategy* and 2) *Joint Warfighting Science and Technology Plan (JWSTP)*, showing how it plans to achieve the Joint Chiefs of Staff (JCS) *Joint Vision 2010* [Ref. 1 and 2]. *Joint Vision 2010* requires the achievement of 12 joint warfare capability objectives. The Integrated Undersea Surveillance System (IUSS) of the Intelligence, Surveillance and Reconnaissance (ISR) directorate has been primarily concerned with supporting and attaining *Joint Vision 2010*'s first objective, Information Superiority.

Information Superiority combines the capabilities of ISR as well as Command, Control, Communications, Computers and Intelligence (C4I) to acquire and assimilate information needed to dominate and neutralize adversarial forces and effectively employ friendly forces. Included in this objective is the capability for near-real-time awareness of the location and activity of all the forces throughout the battlespace. Battlespace Awareness is one of three operational capabilities required to achieve this objective. The Battlespace Awareness can be broken down further into three specific areas of concern: information acquisition, precision information direction, and consistent battlespace understanding. The JWSTP goes on to state that significant advances will be required to manage the acquisition, simultaneous processing, and parallel dissemination of information in an assured and secure manner. High data rate communications is one area where significant advances need to be made.

The IUSS component of ISR, consisting of fixed, mobile and deployable systems, has been gathering acoustic information on ships operating in the oceans of the world for over 30 years. This information has been primarily kept within the intelligence and surveillance communities due to its quantity and the bandwidth required to transmit it in a timely manner. In recent years, IUSS information has been provided for use in a variety of applications including the monitoring of whale migrations and sounds [Ref. 3]. Upgrades in the processing systems, extensive use of commercial off-the-shelf technology (COTS), and a desire to support tactical littoral warfare provide the opportunity for IUSS to communicate directly with the fleet. In an effort to demonstrate potential solutions to the needs discussed above, the Fixed Surveillance System (FSS) program office of the ISR directorate of the Space and Naval Warfare Systems Command (SPAWAR) participated in the New Attack Submarine (NSSN) Open System Critical Item Test (OSCIT).

This was the second year that the IUSS participated in the NSSN OSCIT. During the first year a terrestrial network was used to transfer acoustic data to the test facility. The objectives of the second year were to: 1) provide a more tactical/realistic IUSS -to-NSSN connectivity; 2) refine and enhance the IUSS acoustic products used in the previous OSCIT and 3) demonstrate the substantial advantage of IUSS sensor correlation to the tactical community by extending the NSSN sensor horizon. The IUSS plan for the OSCIT test included the use of a point-to-point high data rate (1.288 Mbps and higher)

satellite channel to deliver IUSS products and near real-time acoustic information using a Very Small Aperture Terminal (VSAT).

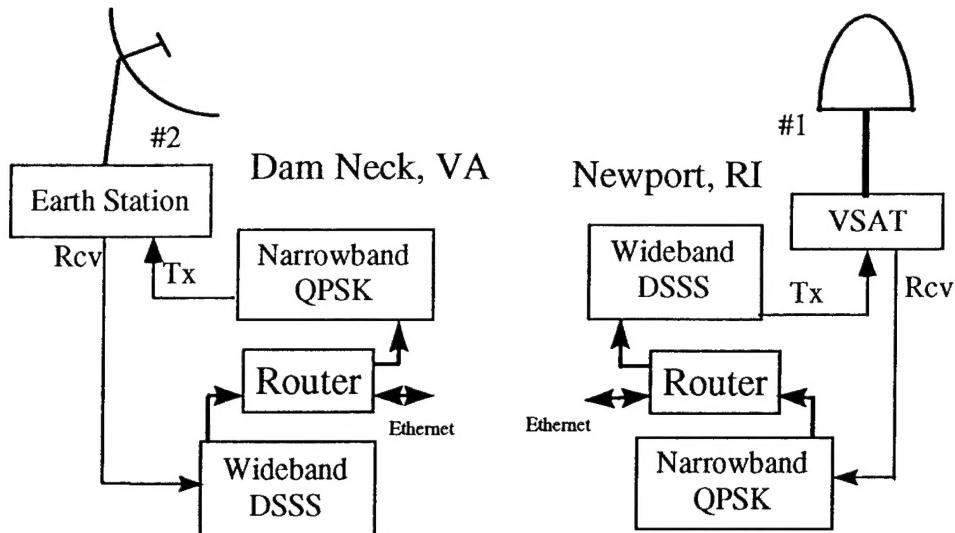


Figure 1: OSCIT Earth Station Configuration

The significant feature of the demonstration was the use of the 0.6 meter VSAT. A submarine would be incapable of carrying the larger satellite dishes in use by the surface fleet. The VSAT's size alone provided more realism to the entire demonstration. The OSCIT demonstrated that the VSAT was capable of routing classified and unclassified network data consisting of standard Internet applications, desktop Video-Teleconferencing (VTC) and JMCIS data. This paper addresses the configuration, bit error rate testing, and the results obtained during the demonstration.

## 2. TEST CONFIGURATION

The OSCIT required a system configuration with two SATCOM earth stations, both shown in Figure 1.

- 1) NRL's VSAT configured for full duplex operation, picture 1, and
- 2) the COMSAT Radiation Systems Inc. (CRSI) Triband Transportable Satellite Earth Terminal, picture 2, configured to support spread spectrum communications.

Terminal #1, the VSAT, was located on the roof of the NSSN test facility at the Naval Undersea Warfare Center (NUWC) in Newport, RI. Terminal #2 was located at the Naval Ocean Processing Facility (NOPF) in Dam Neck, VA. Both terminals were operated by personnel from the NRL with assistance from contractors.

The VSAT transmitted a Direct Sequence Spread Spectrum (DSSS) uplink signal using Binary Phase-Shift Keying (BPSK) modulation (herein referred to as the DSSS signal) and received a narrowband Quadrature Phase-Shift Keying (QPSK) signal radiated



**Picture 1.** NRL's 0.6m VSAT configured to provide HDR WAN connectivity between LANs at NOPF and NUWC



**Picture 2.** COMSAT Radiation Systems Inc. (CRSI) Triband 2.4m Transportable Satellite Earth Terminal configured by NRL to support spread spectrum communications and WAN services.

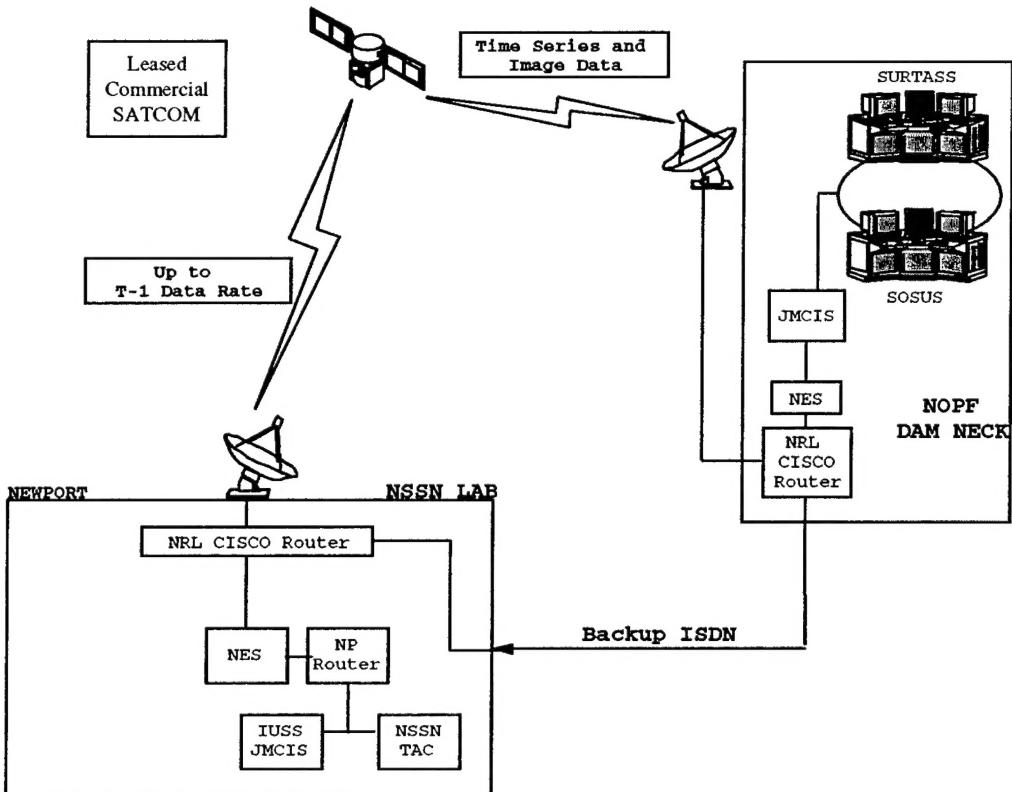


Figure 2: NSSS OSCIT layout including workstations

from the CRSI Triband Transportable Satellite Earth Station. Both signals coexisted in the same satellite transponder. Bit Error Rates (BER) and data transmission rates were measured throughout the demonstration. The signals and results are addressed later in this paper.

Figure 2 diagrams the network configuration. Encryption and security were performed by the Motorola Network Encryption System (NES). The NES is a COTS product with an encryption capacity rated at 1 Mbps. Satellite services were provided by Orion Atlantic on the Orion-1 Satellite, transponder 21.

## 2.1 VSAT STATION

The VSAT terminal was comprised of a Sea-Tel Television Receive Only (TVRO) articulating antenna system designed for at-sea use with a 0.6 meter diameter antenna that was specifically modified by NRL to support both transmitting and receiving subsystems. A block diagram of the configuration is shown in Figure 3. The system includes a downconverter and QPSK modem to demodulate the narrowband signal being transmitted from Dam Neck. It also includes the DSSS modem with an upconverter to convert the modulator output from 2.4 GHz to Ku-band for transmission. [Ref. 4]

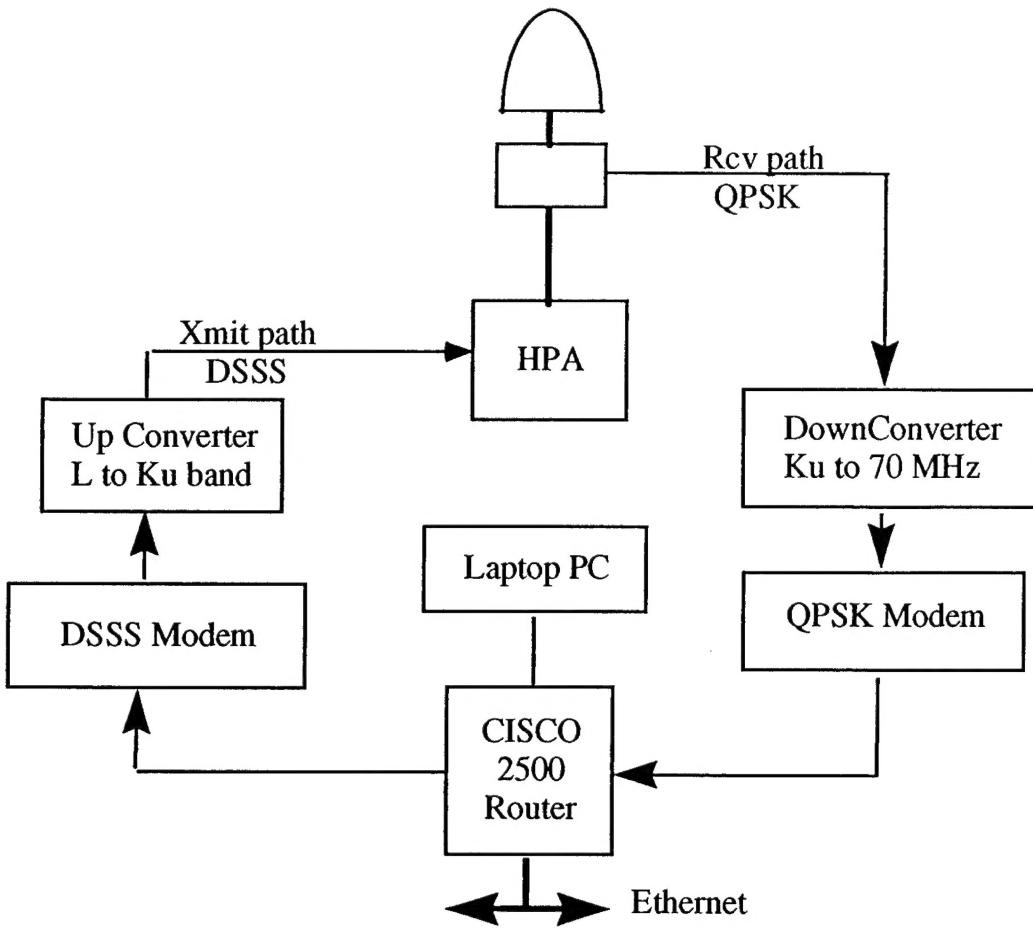


Figure 3: VSAT Terminal Configuration

## 2.2 EARTH STATION

A 2.7 meter earth station was used for transmitting the QPSK signal and receiving the DSSS signal. A Low Noise Amplifier (LNA) was mounted at the receive antenna to improve system noise performance. The transmit and receive paths used low loss waveguide and coaxial equipment, respectively, to connect the antenna to the equipment. Figure 4 shows the equipment configuration of the earth station.

## 2.3 ISDN

Figure 2 includes an ISDN circuit providing 128 kbps bandwidth for data transmission. Although this did not provide the bandwidth of the satellite system for the OSCIT, it provided two valuable functions. The first was a back-up circuit for the acoustic data transmission in case there were any failures with the SATCOM system. The router was configured in such a manner as to automatically "fall-back" to ISDN if the SATCOM link was unavailable. Secondly, it allowed for extended testing during the hours when the satellite transponder was not available.

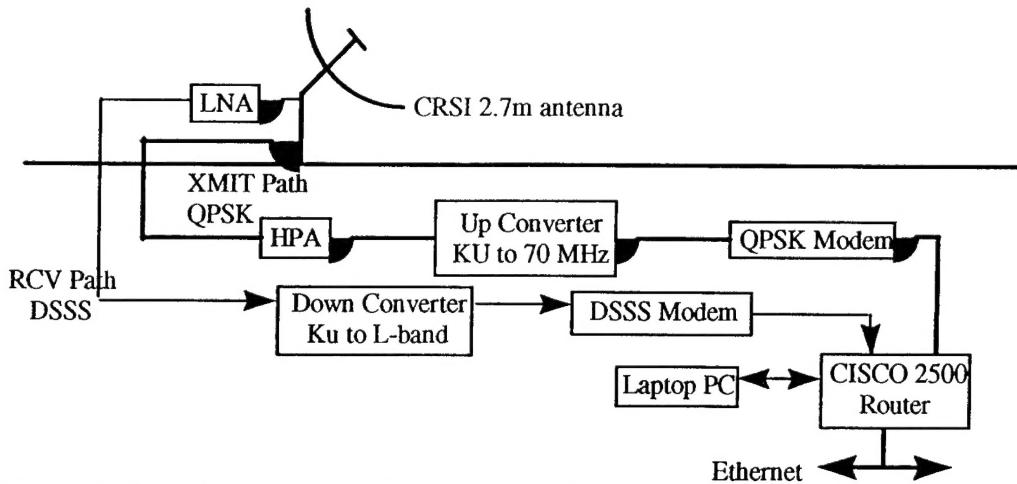


Figure 4: CRSI Transportable Satellite Earth Station Configuration

### 3. SIGNALS

As noted previously, two types of signals were used for the OSCIT: QPSK and DSSS. The QPSK signal was transmitted from the earth station located in Dam Neck, VA. The system was configured in this manner because a shore station typically can accommodate a larger antenna (i.e. more gain), better enabling it to achieve a required carrier to noise (C/N) ratio while maintaining ITU guidelines for interference at adjacent satellites. Higher C/N is required because the QPSK signal is capable of achieving the higher data rates for a given bandwidth only as long as there is sufficient power to keep the BER low [Ref. 6].

The transmission from the VSAT located in Newport, RI utilized a DSSS signal, which is a subset of Code Division Multiple Access (CDMA). Properties of CDMA systems that make them advantageous include:

1. low power spectral density to enable the use of wider beam (i.e. smaller dish) antenna,
2. reduced time coordination constraints for demand assigned networked applications,
3. supporting multiple access with increased signal collision capture capability,
4. graceful performance degradation as links deteriorate (due to fading, congestion, jamming),
5. low probability of intercept when operated at low data rates with large spreading gains,
6. antijam capabilities to narrowband interference. [Ref. 7]

CDMA was not employed during the OSCIT because High Data Rate (HDR) CDMA SATCOM modems do not commercially exist. NRL has ongoing research to develop and deploy HDR SATCOM modems for the fleet to support HDR multimedia networks

aboard ships and forward deployed forces. Naval Research and Development (NRaD) is conducting investigations into exploiting the Low Probability of Intercept (LPI) aspects of CDMA.

#### 4. RESULTS

The system tests were conducted with the VSAT radiating the HDR DSSS signal and the earth station radiating the QPSK signal. Measurements were reported via the CISCO routers, five minute weighted average input data rates and input error rates, and modem front panel display, corrected BER, recorded at fixed time intervals throughout the tests. The tests consisted of FTP data transfers and/or VTC used to simulate a network with full offered load. The maximum theoretical data rate for the QPSK signal was set to be 1.544 Mbps, while the DSSS signal was set to 1.288 Mbps.

The first test was performed recording data rate and computing BER from NUWC to NOPF Dam Neck, primarily testing and attempting to fully load the DSSS link. The average data rate achieved was 1.144 Mbps with a BER average of  $2 \times 10^{-7}$ . The data rate reached a peak of 1.222 Mbps. This result was just shy of the 1.288 Mbps objective. The measurements are shown in Figures 5 and 6.

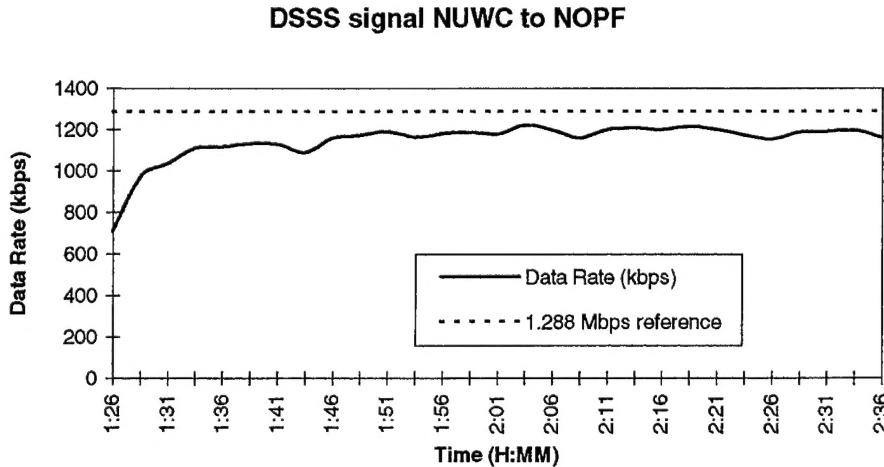


Figure 5: Measured data rates from NUWC to NOPF for the 1.288Mbps DSSS signal.

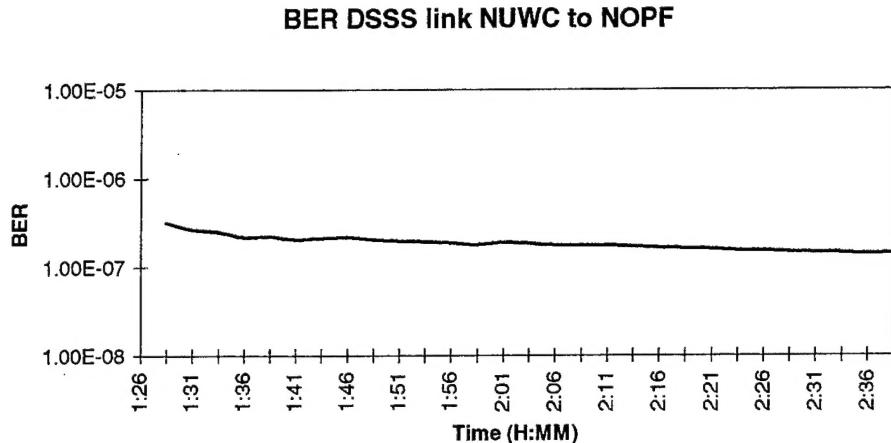


Figure 6: Computed BER for 1.288Mbps DSSS link from NUWC to NOPF.

The second test measured the same information, but full loading was placed on the QPSK signal transmitted from NOPF and received at NUWC. This time the data rate average dropped to 1.120 Mbps, but reached a peak value of 1.471 Mbps, Figure 7. During the second test the BER averaged  $1.4 \times 10^{-6}$ , which is just above the desired objective, Figure 8.

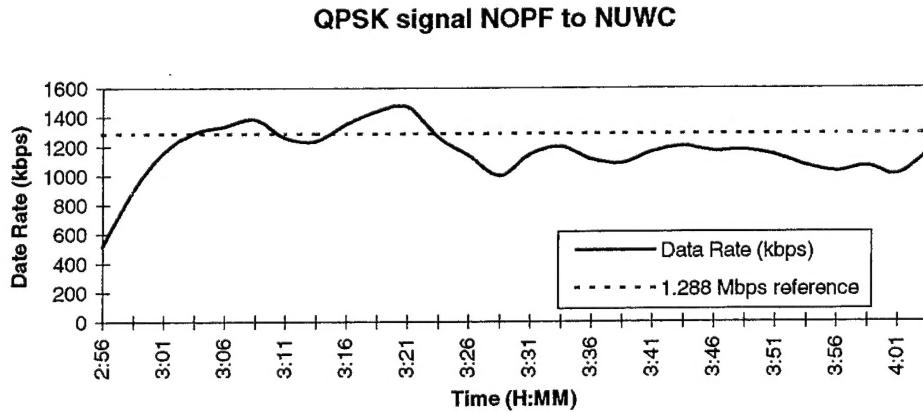


Figure 7: Measured data rates over the 1.544Mbps QPSK signal from NOPF to NUWC.

The last test was performed as a result of a configuration change requested by the OSCIT. The OSCIT directors requested that the VTC capability be moved to inside the lab. This change necessitated that the VTC data be routed through the NES. The previous configuration as noted in Figure 2 encrypted only the acoustic and not the VTC or FTP test data. Degradation in the throughput was noted immediately, but could not be

### BER QPSK link NOPF to NUWC

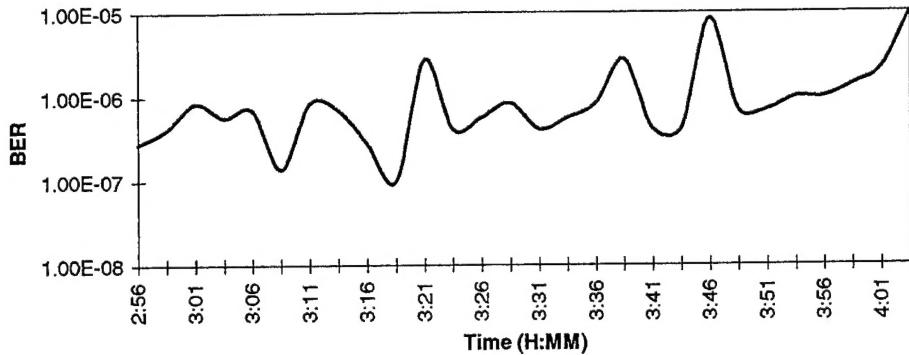


Figure 8 : Measured corrected (7/8 rate Reed-Solomon FEC) BER for 1.544Mbps QPSK link NOPF to NUWC

thoroughly investigated during the demonstration. Satellite time ran out prior to completing a full investigation. Initial indications were that the NES was not able to handle the encryption of some types (UDP vs. TCP) of IP data traffic as efficiently as others. The only noticeable effect during the short testing period was on the VTC circuit. Acoustic data and image transfer, both of which are relatively low data rate and insufficient to fully load the network, appeared to have no problems with the reduced rates. Figure 9 clearly shows a nearly 50 percent reduction in the data transfer rate capabilities when attempts were made to fully load the network, using a combination of FTP and VTC data. The BER on this test run did improve, as shown in Figure 10.

### NES data NOPF to NUWC

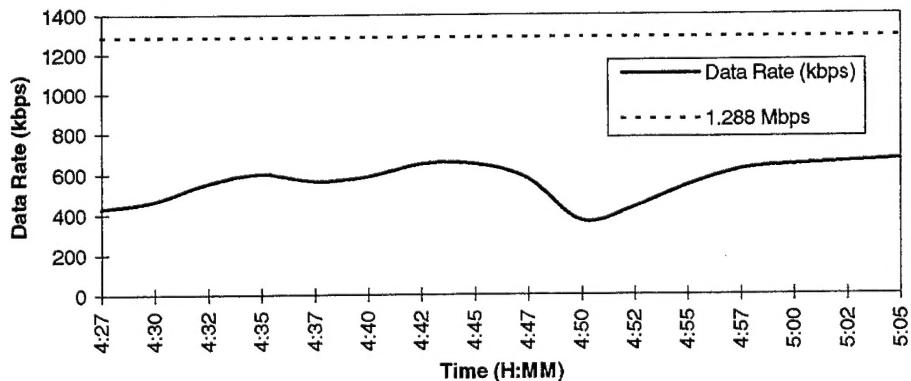


Figure 9: Measured data rate from NOPF to NUWC for 1.544Mbps QPSK signal with full encryption through NES.

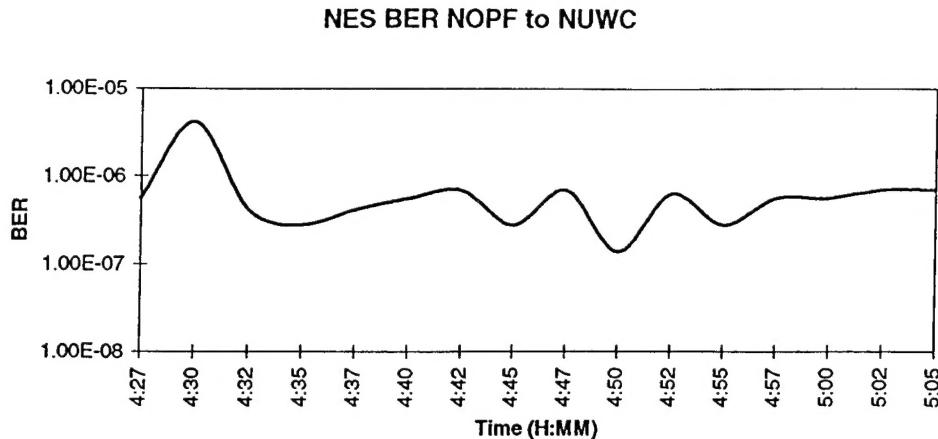


Figure 10: Measured corrected (7/8 rate Reed-Solomon FEC) BER from NOPF to NUWC for 1.544Mbps QPSK signal with full encryption through NES.

## 5. CONCLUSIONS

This was the first successful demonstration of the VSAT in accomplishing full duplex network connectivity. Previous tests had used the VSAT in a simplex mode [Ref. 8]. The system did achieve higher rates than previously recorded, but on average the data rates achieved did not exceed the 1.288 Mbps considered to be the lower extreme for HDR circuits. The Bit Error Rate and data transfer tests demonstrated that a VSAT terminal could consistently support multimedia IP traffic, effectively serve as a WAN connection between LAN, and that VSATs are ideally suited for situations requiring significant satellite data throughput from a small-sized terminal.

Throughput performance for the spread spectrum link was limited by the commercial modems used in the demonstration and by a lack of forward error correction on those links. Higher data rate DSSS modems, as well as spread spectrum modems supporting multiple access (CDMA), are emerging in government labs and as commercial products. Improved BER performance is possible through the incorporation of forward error correction (FEC) codes in the DSSS modulator and demodulator.

The significant reduction in the data transmission during the last test was believed to be caused by the poor performance of the NES. The NES is rated at 1 Mbps, but appeared to be the cause of the reduction. More satellite time and a further investigation of the functions and setup of the NES are required to ensure the exact cause and potential NES solutions. Alternate COMSEC devices, like FASTLANE and KIV 7, to support satellite based networks are components of ongoing research efforts.

Overall the demonstration was a success. Most of the comments made by observers of the demonstration were positive. All were impressed by the capabilities of

the VSAT system. It was suggested that future demonstrations and investigations should be attempted using the VSAT on mobile platforms, trying to reduce the size of the dish to 16 inches or less, increasing the number of VSAT nodes, and/or increasing the network data rate to potentially 45 Mbps.

As mentioned previously, NRL has ongoing research efforts into HDR SATCOM networks using CDMA and VSAT technology. In addition, the Submarine Communications Program office, PMW 173, of SPAWAR is leading the SUB HDR program, designing a multiple use 16 inch parabolic antenna to operate in both the SHF and EHF frequency bands.

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